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Sea Breeze – Induced Mesoscale Systems and Severe Weather Final Report – NASA Grant No. NAG5-359

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1. Introduction

~~Supported~~ by NASA grant ~~No.~~ NAG5-359 ~~we have been investigating~~ sea-breeze-deep convective interactions over the Florida peninsula WERE INVESTIGATED using a cloud/mesoscale numerical model. The objective ~~of~~ this study was to gain a better understanding of sea-breeze and deep convective interactions over the Florida peninsula using a high resolution convectively explicit model and to use these results to evaluate convective parameterization schemes. ~~We have completed~~ a two-dimensional numerical investigation of Florida convection WAS COMPLETED and this work has been accepted for publication (Nicholls *et al.*, 1990a). In this report ~~we summarize~~ the results of this paper and our evaluation of the Kuo and Fritsch-Chappell parameterization schemes. ARE SUMMARIZED & EVALUATED.

2. Convectively explicit simulations

2.1 Model

The non hydrostatic version of the Colorado State University Regional Atmospheric Modeling System (CSU-RAMS) is used in this study. The cloud model includes parameterizations of cloud water, rainwater, pristine ice crystals, snow, and graupel. The surface parameterization of vertical heat, vapor, and momentum fluxes is based on the Louis (1979) scheme. The surface values of temperature and moisture are predicted from the upper-level of a multi-level prognostic soil model developed by McCumber and Pielke (1981) and modified for RAMS by Tremback and Kessler

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(1985). The longwave and shortwave parameterization developed by Chen and Cotton (1983) is employed. It takes into account both clear air and cloudy air conditions.

The horizontal grid spacing is 1 km and the vertical resolution is 400 m at the surface which is gradually stretched to 1 km at the top of the model. The domain size is 400 km in the horizontal and 21 km in the vertical. The land-surface is 200 km in width surrounded by 100 km of water on either side. A rigid lid is used for the upper boundary condition. A weak dissipative layer 7 km in depth is included at the top of the domain to reduce reflection from the upper boundary. The lateral boundaries incorporate a mesoscale compensation region (MCR – see Tripoli and Cotton, 1982). The MCR is included to provide a large-scale mass balance adjustment due to circulation trends generated within the interior model domain. Lateral boundaries of the domain additionally incorporate the Klemp-Lilly (1978) radiation boundary condition to allow propagation of gravity waves through the interior model walls. In order that any tendency for small cells to develop is not inhibited by the use of a horizontally homogeneous basic state, small randomly specified temperature perturbations (<0.2°C) are initially introduced into the first level above the surface.

2.2 Environments used to initialize the model

The environmental wind profiles used in this study are based mainly on the results of Blanchard and Lopez (1985) who classified undisturbed days into three types. Radar echoes and the synoptic situation for these types are described in detail in their paper. The Type 1 situation is characterized by major development of convection along both coasts due to low-level uplift at the sea-breeze fronts. The east coast convection moves inland fairly rapidly, whereas the west coast convection moves more slowly. Merging of the radar echoes usually occurs west of the peninsula. The convection is strongest in the interior of the peninsula and diminishes in the early evening. Type 2 days start out in a fashion similar to Type 1 days. However, the east coast convection moves inland very quickly, whereas the west coast convection is very weak. Later in the afternoon, 1500-1800 EDT, convection becomes more widespread, but is concentrated in the western half of the peninsula. It eventually moves over the sea. On Type 3 days, convection starts earlier than on Type 1 or Type 2 days. In

this case, it is the west coast convection that moves inland quickly, eventually merging with the convection on the east coast. Type 3 days exhibit a higher echo area coverage and dissipation takes place later in the day.

The wind component perpendicular to the coast for Type 1 days has weak easterlies ($\sim$3 m s^{-1}) in the lower and mid-troposphere. Type 2 days have stronger easterlies ($\sim$5 m s^{-1}), whereas Type 3 days have weak westerlies near the surface ($\sim$1 m s^{-1}) increasing to $\sim$4 m s^{-1} at 600 mb. In addition to these three types, we include simulations for no initial winds, moderate low-level shear (5 m s^{-1} easterlies at the surface, decreasing to zero at 2.5 km), and a weak low-level jet.

The thermodynamic profile is based on the soundings for 17 July, 1973 during FACE (Florida Area Cumulus Experiment). Variations in moisture content were found by Blanchard and Lopez for the three types they classified, so simulations were carried out to test the sensitivity to this parameter. An experiment was made with a more stable environment which is usually the case for Type 2 days. A simulation was also performed for a modified boundary layer. For this case, the surface temperature was increased by 2°C and the surface moisture by 1.0 g kg^{-1}. These perturbations linearly decrease to zero at a height of 1 km. Sensitivity tests to the surface fluxes were also carried out by specifying a very dry and a very moist soil layer 110% and 80% of the maximum volumetric moisture content, respectively. Finally, a simulation was run without any microphysics.

The simulations are begun at 800 EDT and end at 2000 EDT. A sensitivity test to starting the simulation at sunrise instead of at 800 EST indicated only small differences to the sea breeze circulation.

2.3 Results

The Type 1 wind profile produces strong convection near the west coast which remains slightly inland during its intense stage. The Type 2 wind profile also produces intense convection near the west coast, but it is quickly advected out to sea. This convection was stronger than observations indicate for Type 2 days, suggesting that the drier mid-level air and more stable lapse rates that

typically exist on these days are the main factors responsible for reducing system intensity. Sensitivity tests to these parameters did indeed produce much weaker systems as might be expected. The Type 3 wind profile simulation produced strong convection on the east side of the peninsula in agreement with observations. However, convection did not develop earlier than for the other two cases and it decayed too soon. Increasing the mid-level moisture (which is typically found on Type 3 days) produced stronger convection earlier in the day, in better agreement with observations, however, convection did not last longer. Blanchard and Lopez (1985) note that a 700 mb trough typically exists over north Florida on Type 3 days. Hence, it is possible that synoptic scale forcing is responsible for the longevity of convection on Type 3 days. These simulations did not produce extensive stratiform regions consistent with observations of Florida convection.

The fairly modest changes to the wind structure made in this study did not result in radically different types of systems forming. Results for these cases support the conclusion that the low-level winds are the main control in determining where rapid convective development occurs. The weak low-level jet case momentarily produced a system that resembled a squall line. However, the systems lifetime seemed to be too short for it to develop an extensive stratiform region and the pronounced front-to-rear flowing updraft and rear-to-front flowing downdraft that is typically associated with squall lines. Hence, momentum transports tend to be relatively small compared to squall lines with the circulation taking the form of fairly symmetrical low-level inflow and upper-level outflow on either side of the system.

Increasing the low-level temperature and moisture content led to the earlier development of convection. A number of fairly intense cells formed in this simulation and convection was still strong at 2000 EST. The dry soil simulation produced rapidly developing sea-breezes which moved inland quickly, whereas the moist soil case produced a much more slowly developing sea-breeze. Surprisingly, the total rainfall over the peninsula for the dry soil case was more than for the moist soil. Presumably, this is because the faster moving sea-breezes for the dry soil case provide stronger low-level convergence to force the convection.

Shallow cells developed early on in the simulations, between the converging sea-breeze fronts. These cells caused heat to be transported upwards more rapidly and produced low-level drying and moistening above. As the outer cells developed at the sea-breeze fronts the smaller cells in between were suppressed. These deep outer cells tended to move with the mid-level winds and to be left behind by the rapidly moving sea-breeze fronts which would then initiate one or two new cells as they converged. Typically, one cell near the center of convergence would develop explosively, and the outer cells would usually decay although merger with one of the outer cells occasionally occurred. The initial rapid development was followed by a weakening in intensity, probably due to precipitation falling back into the updraft and this produced two oppositely travelling gravity waves, having a propagation speed of $\sim$25-30 m s^{-1}. A reduction in the heating rate appears to cause two oppositely moving regions of upward motion (with magnitudes much less than convective updraft velocities) to separate away from the convection. This leads to adiabatic cooling of previously subsided air and forms the two oppositely moving gravity waves. These disturbances have a roll-like structure. Downward motion at the leading edge of the disturbance produces adiabatic warming whereas upward motion at the back edge leads to adiabatic cooling. Most of the large perturbations are associated with this type of fast moving gravity wave and so when convection decays and they propagate away the environmental structure tends to return to the initial state. A simple analytic model of this type of thermally forced gravity wave and a term analysis which shows that it is predominantly linear in character is presented in Nicholls *et al.* (1990b,c).

Apparent heat and moisture budgets averaged across the whole domain were determined. At 1500 EST Q1 is maximized in the lower troposphere. By 1800 EST this maximum has shifted to the upper troposphere. As convection decays, weak warming occurs aloft and weak cooling below mid-levels. During the deep convective stage, large-scale drying occurs which is maximized at low levels.

The net radiational heating at cloud top underwent a transition from warming during the mid-afternoon to cooling during the early evening. This change in sign of the heating and its relatively

small magnitude compared to latent heating rates indicate that its effect on the dynamics of the system was quite small.

Rainfall rates were compared with observational studies of Florida rainfall (Ulanski and Garstang, 1978; Cooper *et al.*, 1982; Burpee and Lahiff, 1984). The simulated rainfall rates agree fairly well with observed values although they may have been slightly on the high side. Slightly excessive rainfall rates might be expected in a two-dimensional model as shown by Nicholls and Weissbluth (1988) for the case of a tropical squall line.

In summary, the two-dimensional model compares favorably with observations, has been used to test the sensitivity to a range of environmental conditions, and has shed light on some of the dominant dynamic and physical processes occurring.

Three dimensional simulations were made with a domain size of 120 km in length and 20 km in width, with a peninsula size of 80 km (Song and Pielke, 1988a,b). The domain was a channel with periodic boundaries on the sides and open boundaries at the ends. A grid resolution of 750 m was used both in the horizontal and vertical, and the simulation was run for 4 h. Two lines of convection formed on either side of the peninsula and moved inland. Strong convergence occurred as the sea-breeze fronts converged in the center of the peninsula. These results were similar to those obtained in a two-dimensional simulation. Fully three-dimensional simulations of Florida convection would be very useful for ascertaining the effects of the shape of the peninsula and Lake Okeechobee on convective patterns.

3. Evaluation of parameterization schemes

3.1 A three-dimensional simulation using a convective parameterization scheme.

Song and Pielke (1988a, b) developed a convective parameterization having some of the better features of the schemes used by Fritsch and Chappell (1980), Zhang and Fritsch (1986), and Frank and Cohen (1985). A three-dimensional simulation of a synoptically undisturbed day was made using this parameterization scheme. In the early afternoon convection started to develop over the

west coast in agreement with observations. However, convection associated with the east coast sea-breeze was not simulated. In the late afternoon intense convection over the west coast was well simulated. However, the model produced too strong convection to the southeast. Although there were some definite agreement of Song and Pielke's results with the observed convective activity, there were some differences. This was the motivation for making convectively explicit simulations which would enhance the understanding of the sea-breeze-deep convective interaction and allow for a more precise and methodical evaluation of parameterization schemes.

3.2 Diagnostic evaluation of the Kuo and Fritsch-Chappell parameterization schemes

3.3 Diagnostic evaluation

The diagnostic method is to take horizontal averages of fields generated by convectively explicit simulations and use this as input into parameterization schemes. The Q1 and Q2 budgets obtained are then compared with those of the convectively explicit simulations. Presently, the Kuo and Fritsch-Chappell cumulus parameterization schemes are being investigated (Kuo, 1974; Fritsch and Chappell, 1980). In addition to the original Fritsch-Chappell scheme, an improved scheme modified by Craig Tremback in our group, is being studied. The modified scheme is energy conserving unlike the original scheme and uses a more realistic lateral detrainment assumption at cloud top. Q1 and Q2 budgets were obtained for the Type 1 wind profile discussed in Section 3 for various horizontal scales and compared with those predicted by the parameterization schemes. For horizontal scales greater than 100 km the parameterization schemes give reasonable agreement with the Q1 profile determined from the convectively explicit simulation. However, for smaller horizontal averaging areas the magnitude of the heating rate is significantly underestimated. At 4:00 p.m. when rapid convective development is taking place, the original Fritsch-Chappell scheme gives excessive heating in the lower stratosphere. This is because the original Fritsch-Chappell scheme assumes that the mass flux doubles from cloud base to cloud top. This results in compensating subsidence occurring in the stable lower stratosphere causing large warming. At 5:00 p.m. very serious discrepancies

between the simulated Q1 budget and those predicted by the parameterization schemes arise. A 20 km horizontal average around the area of intense convection does not even result in the activation of the cumulus parameterization schemes. This is because in the region of strong convection there has been significant low-level cooling and mid-level warming, so that the environment used as input into the parameterization schemes does not have enough convective instability to activate them. In the convectively explicit simulation at this time the cumulonimbus is situated over the west side of the peninsula and is feeding off low-level air coming from the east. Evaporational cooling has formed a cold pool and strong convergence occurs where it collides with the warm low-level easterlies. Significant convection is maintained for the next couple of hours. Obviously, the parameterization schemes are giving serious discrepancies with the simulated Q1 budgets on a 20 km scale. During the deep convective stage, large-scale mid-level drying occurs, which is maximized at fairly low-levels ($\sim$2 km above the surface). However, the cumulus parameterization schemes are giving drying rates maximized at the surface with weak mid-level moistening rates. Clearly, there are also significant differences in the Q2 budgets which need to be addressed.

3.4 Prognostic evaluation

At present the Kuo scheme is available in the new version of RAMS and we are in the process of implementing the Fritsch-Chappell scheme. Although, realizing that the Kuo scheme is designed for fairly large scales $\geq$100 km, we decided to run a simulation using a 20 km resolution as a prelude to using the Fritsch-Chappell scheme. A convective time scale of 20 minutes was chosen and an activation cloud base velocity of 5 cm s^{-1}. Results were sensitive to the activation cloud base vertical velocity chosen. A value of 10 cm s^{-1} did not result in the activation of the convective parameterization, whereas a value of 1 cm s^{-1} activated convection too soon and produced very noisy looking fields. The version of the Kuo scheme used includes a crude downdraft parameterization. Similar to the convectively explicit simulation the surface warming produces west and east coast sea-breezes. Convergence and upward motion occurs on the west side of the peninsula at 3:00 p.m., approximately the same time as occurred for the convectively explicit simulation, and

the convective scheme is activated in this region. Unlike the early stage of the convectively explicit simulation, however, the upward motion is maximized in the upper troposphere instead of at low levels. At 5:00 p.m. two cells of upward motion have developed. One of these is situated to the east of the center of the peninsula and has no counterpart in the convectively explicit simulation. Furthermore, a cold pool is not formed and the mid-level warming is much weaker than occurs in the convectively explicit simulation. By 7:00 p.m. upward motion is very weak and is situated over the east side of the peninsula. There is still a significant amount of surface warm air left, unlike the convectively explicit simulation.

4. Summary

The two-dimensional convectively explicit simulations appear to give reasonable agreement with the characteristic types of convective events occurring on undisturbed days. Sensitivity tests were carried out for a wide range of environmental conditions. Results of these two-dimensional convectively explicit simulations were used to evaluate the Kuo and Fritsch-Chappell parameterization schemes, both diagnostically and prognostically. The results of this investigation suggest:

1. That because the convectively explicit model gives good agreement with observations, full three-dimensional simulations with this model could be expected to lead to a better understanding of the influence of the shape of the peninsula, Lake Okeechobee, directional wind shear, inhomogeneous soil type, vegetation and soil moisture on determining convective patterns.

2. Although the apparent heat budgets for the Kuo and Fritsch-Chappell schemes appear reasonable for a scale of $\sim$100 km, serious discrepancies arise as the scale is reduced. Prognostic simulations using current parameterization schemes may initialize convection in the right place and at the right time, but the subsequent location and strength of convection is likely to be in serious error. It is possible that these discrepancies may not be so large if there

is continuous synoptic scale forcing. The method used in this study would be valuable for aiding in the design of an improved parameterization scheme.

5. References

Blanchard, D.O. and R.E. Lopez, 1985: Spatial patterns of convection in south Florida. *Mon. Wea. Rev.*, **113**, 1282-1299.

Burpee, R.W. and L.N. Lahiff, 1984: Area-average rainfall variations on sea-breeze days in south Florida *Mon. Wea. Rev.,* **112**, 510-519.

Chen, C. and W.R. Cotton, 1983: A one-dimensional simulation of the stratocumulus-capped mixed layer. *Bound.-Layer Meteor.*, **25**, 289-321.

Cooper, H.J., M. Garstang, and J. Simpson, 1982: The diurnal interaction between convection and peninsula-scale forcing over south Florida. *Mon. Wea. Rev.,* **110**, 486-503.

Frank, W.M. and C. Cohen, 1985: Properties of tropical cloud ensembles estimated using a cloud model and an observed updraft population. *J. Atmos. Sci.*, **42**, 1911-1928.

Fritsch, J.M. and C.F. Chappell, 1980: Numerical prediction of convectively driven mesoscale pressure systems. Part I: Convective parameterization. *J. Atmos. Sci.*, **37**, 1722-1733.

Klemp, J.B. and D.K. Lilly, 1978: Numerical simulation of hydrostatic mountain waves. *J. Atmos. Sci.*, **35**, 78-107.

Kuo, H.L., 1974: Further studies of the parameterization of the influence of cumulus convection on large-scale flow. *J. Atmos. Sci.*, **31**, 1232-1240.

Louis, J.F., 1979: A parametric model of vertical eddy fluxes in the atmosphere. *Bound.-Layer Meteor.*, **17**, 187-202.

McCumber, M.C. and R.A. Pielke, 1981: Simulation of the effects of surface fluxes of heat and moisture in a mesoscale numerical model - Part I: Soil layer. *J. Geophys. Res.*, **86**, 9929-9938.

Nicholls, M.E. and M.J. Weissbluth, 1988: A comparison of two-dimensional and quasi-three-dimensional simulations of a tropical squall line. *Mon. Wea. Rev.*, **116**, 2437-2452.

Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1990a: A two-dimensional numerical investigation of the interaction between sea-breeze and deep convection over the Florida peninsula. *Mon. Wea. Rev.*, (accepted).

Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1990b: Thermally forced gravity waves. *J. Atmos. Sci.* (to be submitted).

Nicholls, M.E., W.R. Cotton, and R.A. Pielke, 1990c: The formation of deep gravity waves by a mesoscale convective system. *Extended Abstracts Volume, Fourth Conference on Mesoscale Processes*, Boulder, Colorado. June 25-29, 1990.

Song, J.L. and R.A. Pielke, 1988a: The influence of deep cumulus convection of sea breeze dynamics over south Florida. Part I: Model development. Atmospheric Science Paper # 426, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.

Song, J.L. and R.A. Pielke, 1988b: The influence of deep cumulus convection of sea breeze dynamics over south Florida. Part II: Model application. Atmospheric Science Paper # 426, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.

Tremback, C.J. and R. Kessler, 1985: A surface temperature and moisture parameterization for use in mesoscale numerical models. Preprints, 7th Conference on Numerical Weather Prediction, *Amer. Meteor. Soc.,* June 1985, Montreal, Canada, 17-20.

Tripoli, G.J. and W.R. Cotton, 1982: The Colorado State University three-dimensional cloud/mesoscale model - 1982. Part I: General theoretical framework and sensitivity experiments. *J. Rech. Atmos.*, **16**, 185-220.

Ulanski, S.L. and M. Garstang, 1978: The role of surface divergence and vorticity in the life cycle of convective rainfall. Part I. Observations and analysis. *J. Atmos. Sci.*, **35**, 1047-1062.

Zhang, D.-L. and J.M. Fritsch, 1986: Numerical simulation of the meso-β scale structure and evolution of the 1977 Johnstown flood. Part I: Model description and verification. *J. Atmos. Sci.,* **43**, 1913-1943.

6. Publications Which Acknowledge NASA Grant No. NAG5-359

6.1 Reviewed Papers

Kessler, R.C., D. Eppel, R.A. Pielke and J. McQueen, 1985: A numerical study of the effects of a large sandbar upon sea breeze development. *Arch. Meteor. Geophys. Bioklim.*, Series A, **34**, 3-26.

Lipton, A.E. and R.A. Pielke, 1985: Vertical normal modes of a mesoscale model using a scaled height coordinate. *J. Atmos. Sci.*, **43**, 1650-1655.

Mahrer, Y. and M. Segal, 1985: On the effect of islands geometry and size on inducing sea breeze circulation. *Mon. Wea. Rev.*, **113**, 170-174.

Michaels, P.J., 1985: Anomalies of mid-tropospheric heights and persistent thunderstorm patterns over Florida. *J. Climatol.*, **5**, 529-542.

Michaels, P.J., R.A. Pielke, J.T. McQueen and D.E. Sappington, 1987: Composite climatology of Florida summer thunderstorms. *Mon. Wea. Rev.* **115**, 2781-2791.

Nicholls, M.E., 1990: Thermally forced gravity waves. Part I: A linear model of mesoscale convective systems. *J. Atmos. Sci.*, (submitted).

Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1990: The energetics of thermally-forced gravity waves and sound waves. *J. Atmos. Sci.* (to be submitted).

Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1990: Thermally forced gravity waves. *J. Atmos. Sci.* (to be submitted).

Nicholls, M.E., R.A. Pielke, and W.R. Cotton, 1990: A two-dimensional numerical investigation of the interaction between sea-breezes and deep convection over the Florida peninsula. *Mon. Wea. Rev.*, (accepted).

Pielke, R.A., A. Song, P.J. Michaels, W.A. Lyons, and R.W. Arritt, 1990: The predictability of sea-breeze generated thunderstorms. *Atmosfera*, (accepted).

Segal, M. and R.A. Pielke, 1985: The effect of water temperature and synoptic winds on the development of surface flows over narrow, elongated water bodies. *J. Geophys. Res.*, **90**, 4907-4910.

Segal, M., J.F.W. Purdom, J.-L. Song, R.A. Pielke and Y. Mahrer, 1985: Evaluation of cloud shading effects on the generation and modification of mesoscale circulations. *Mon. Wea. Rev.*, **114**, 1201-1212.

Segal, M., R. Avissar, M.C. McCumber and R.A. Pielke, 1988: Evaluation of vegetation effects on the generation and modification of mesoscale circulations. *J. Atmos. Sci.*, **45**, 2268-2292.

Song, J.-L., R.A., Pielke and M. Segal, 1986: Vectorizing a mesoscale meteorological model on the CYBER 205. *Environ. Software*, **1**, 10-16.

6.2 Preprints

Segal, M., R.A. Pielke and Y. Mahrer, 1984: Evaluation of Surface Sensible Heat Flux Effects on the Generation and Modification of Mesoscale Circulations. *Proceedings of the Nowcasting II Symposium*, September 3-7, Norrkoping, Sweden, pp. 263-269.

Tremback, C.J. and R.C. Kessler, 1985: A Surface Temperature and Moisture Parameterization for Use in Mesoscale Numerical Models, 7th Conference on Numerical Weather Prediction, June 17-20, Montreal, Canada.

Pielke, R.A., J.-L. Song, M. Segal, P.J. Michaels, W.A. Lyons and R.A. Arritt, 1986: The Predictability of Sea Breeze Generated Thunderstorms. *Proceedings of the WMO International Workshop on Rain-Producing Systems in the Tropics and the Extra-Tropics*, San Jose, Costa Rica, July 21-25, 1986, 101-107.

6.3 Chapters in Books

Pielke, R.A. and M. Segal, 1984: Mesoscale circulations forced by differential terrain heating. AMS Intensive Course on Mesoscale Meteorology and Forecasting, Boulder, Colorado, July 8-20, 1984, Chapter 22, 516-548.

Forbes, G.S. and R.A. Pielke, 1985: Use of observational and model-derived fields and regime model output statistics in mesoscale forecasting. Presented at the Nowcasting Symposium at the IAMAP/IAPSO Joint Assembly, August 7, 1985, Honolulu, Hawaii. ESA J.. 207-225.

6.4 Theses

Song, J.-L., 1986: Ph.D. Dissertation. A numerical investigation of Florida's sea breeze - Cumulonimbus interactions. Colorado State University, Department of Atmospheric Science, Fort Collins, Colorado 80523.

6.5 Non-Reviewed Reports

McQueen, J.T. and R.A. Pielke, 1985: A numerical and climatological investigation of deep convective cloud patterns in south Florida. Atmospheric Science Paper No. 389, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado 80523.

Pielke, R.A., M. Segal and J.-L. Song, 1987: Semi-annual progress report on NASA Grant # NAG5-359. February, 1987.

Pielke, R.A., M. Segal and J-L. Song, 1987: Semi-annual progress report on NASA Grant # NAG5-359. August, 1987.

Pielke, R.A., M. Segal, W.R. Cotton and M. Nicholls, 1988: Semi-annual progress report on NASA Grant # NAG5-359. August, 1988.

Song, J.-L. and R.A. Pielke, 1988: The influence of deep cumulus convection on sea breeze dynamics over south Florida, Part I: Model development. Atmospheric Science Paper #426, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.

Song, J.-L. and R.A. Pielke, 1988: The influence of deep cumulus convection on sea breeze dynamics over south Florida, Part II: Model application. Atmospheric Science Paper #427, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado.